

*"The student as worker will be able to meet performance outcomes that include, but are not limited to:*

*. Accessing information - acquiring, organizing, and maintaining data as well as interpreting and communicating information;*

*. Demonstrating interpersonal skills - working on teams, teaching and serving others, leading, negotiating, and working with people from culturally diverse backgrounds;*

*. Using resources - allocating time, money, materials, space, and human resources;*

*. Understanding political systems - operating within social, political and organizational systems, monitoring and correcting performance, and designing or improving systems;*

*. Using technology - selecting and applying technologies to the specific tasks including the use of computers and other emerging technologies to process information."*

*Educating ALL Our Children, A  
Report of the 21st Century  
Education Commission, March  
1992.*

## Insights from Research on the Learning and Teaching of Science

The goal of science teaching is to educate all students in the science needed for today's world. This will necessitate a transformation in the way we think about science education. All of our children and young adults, not just those preparing to be professional scientists, must have an understanding of scientific ways of thinking and science knowledge in order to function in an information age. Learning science helps develop critical thinking skills and gives practice in the use of evidence in decision making. An increasing number of jobs require understanding scientific processes and principles, and most jobs call for problem solving and decision making skills that may be acquired through the study of science. Equally important is the ability for all citizens to make good decisions using a basic understanding of the science and technology behind the various social issues affecting their lives.

### Science Standards: A Valuable Resource for Improved Instruction

To transform science instruction statewide, reaching schools in the various districts as well as private schools, there needs to be agreement on what students ought to know, how it should be presented, and how to measure the results. The setting of national science standards is underway with the work of the National Academy of Science through its National Research Council working with the American Association for the Advancement of Science, the National Science Teachers Association, and other professional scientific societies and the broad constituencies they represent. Working groups drafted standards for curriculum, teaching, and assessment which were publicly released in November of 1994. A consensus process is being followed to encourage broad review and discussion of the draft with a final version planned for late 1995.

The RI Science Frameworks Development team has conducted its work with a close eye on this project of national significance, as well as taking account of the already well-known and highly

regarded national work of the Scope, Sequence and Coordination of Secondary Science Project of the National Science Teachers Association, and Project 2061 of the American Association for the Advancement of Science. Rigorous standards will set the framework for what young Rhode Islanders should know and be able to do when they leave school. Rhode Island is making crucial systemic changes to reach these standards, building on its initial efforts within the Rhode Island Statewide Systemic Initiative in Mathematics and Science. These changes include:

- ◆ expanding the range of state assessments;
- ◆ allowing consolidation of different federal funding streams within a district;
- ◆ promoting school-to-work connections;
- ◆ integrating social services with educational institutions;
- ◆ revising teacher certification and licensure requirements; and
- ◆ associated changes in the structure of science teacher preparation programs within the state.

Research studies show that children who are in schools with high expectations and challenging, "hands-on" curricula learn more than children who are in less demanding educational programs. Most students will work to meet whatever expectations their teachers and families have for them, however high, however low. In science we need a clear consensus on what students should know and be able to do.

The Statement of Principles on School Reform in Mathematics and Science from the U.S. Department of Education and the National Science Foundation states that "all children should receive a challenging education in mathematics and science based on world-class standards beginning in kindergarten and continuing every year through grade 12." The Special Legislative Commission on Mathematics and Science Education, convened by the RI State Legislature, concluded its 1992 report with a primary recommendation that:

"Curriculum frameworks for mathematics and science education, K-16, which align with the NCTM Standards and the AAAS Science for All Americans reports must be developed. These curriculum frameworks will:

- \* provide a vision of high standards for student achievement by including: a) program goals and program outcomes, b) student outcomes, c) teaching strategies, d) related materials and resources, e) assessment strategies which recognize all components of the frameworks
- \* guide the districts in formulating local curricula

- \* provide indicators to gauge the level of success in achieving the stated goals
- \* drive the succeeding recommendations (within the report)
- \* provide a model for post-secondary curriculum frameworks that will ensure a smooth transition from secondary school to college"

This framework and the state mathematics framework are first steps toward realizing this goal.

#### Students Learn by Constructing Knowledge

Research from the cognitive sciences and from science education has transformed our understanding of how children learn. The view of the student absorbing knowledge has shifted to one of the student constructing knowledge, called the "constructivist approach," by being involved in interpreting and understanding new content, and linking new knowledge to existing knowledge in a meaningful way (Shapiro, 1994; Fensham, Gunstone and White, 1994, Steffe and Gale, 1995).

Learners come to new situations with preconceived notions. As children develop, and long before they enter formal education, they need to make sense of the natural world about them. They begin to construct sets of ideas, expectations, and explanations about natural phenomena. Since these ideas are frequently quite different from the ones held by scientists, we sometimes refer to them as naive conceptions. For example, fifth grade students were asked "What is food for plants?" Most students gave replies of "water," "soil," or "plant food" that can be bought in stores. These students had the idea that food for plants was something similar to food for people, rather than plants' need for light to make their own food through the process of photosynthesis (Anderson & Smith, 1984).

Teaching for conceptual change or "teaching for understanding" as it is called, requires different strategies from those usually followed in the classroom. Teachers continually diagnose students' ideas and consider where they are in the process of conceptual change. Students' conceptions are addressed through exploration and discussion. Opportunities are provided for the testing of ideas, even those that are false. Materials are needed that will encourage the student's exploration of a phenomenon as a way of acquiring new knowledge. While research continues on the implications of constructivism for the curriculum and instruction, there is agreement that traditional didactic teaching is not the only effective way to promote conceptual change. Students often remain committed to their alternative conceptions while memorizing new material and doing well on tests, frequently without any real understanding of new concepts.

## Hands-On, Inquiry-Based Science Instruction

In hands-on science instruction the teacher engages the students in questions that require them to think about and apply what they are doing to new situations. The "minds-on" part of instruction comes with dialogue, discussion, and exploration using hands-on materials. Experiences with a particular science phenomenon must be concrete, relevant to the students, and varied.

All hands-on activities require the use of materials. Students learn by doing, using materials such as plants, batteries and bulbs, or water, or instruments such as the microscope, meter stick, or test tube. These instructional materials must be sequenced to facilitate students' construction of meaning. Giving students sets of activities without connections drawn among them leads to isolated bits of knowledge. Therefore, rather than presenting students with bits and pieces of information, and leaving it to them to piece these together, the teacher needs to help students see the interconnections among scientific ideas (Raizen and Michaelson, 1994).

In practice, however, despite the emphasis on "doing science" with the use of instructional materials, textbooks have defined the curriculum. In drawing a comparison one science educator commented: "Teaching with hands-on activities is demanding, but everyone is involved, eager, and active, and participants remember what they have done . . . I never saw a textbook do that" (Haury and Rillero, 1992). Textbooks may have a place in the curriculum as a support for inquiry and experimentation. However, a more experimental base is needed at all levels involving use of instructional materials and equipment and thought-provoking questions and dialogue.

Other material resources are needed to support student exploration of scientific ideas. Children's trade books and magazines are valuable resources to engage students and enrich their understanding of the natural world. Many of these resources are reviewed and evaluated periodically. An annotated bibliography is published as a guide for users by the American Association for the Advancement of Science and the National Science Teachers Association. Relevant films, videos, and computer resources are also important resources for the classroom. In addition, technical support is needed to supply teachers with science equipment, hardware, materials and to maintain and manage these resources. Updated facilities and effective maintenance plans must be created within schools in concert with these resources if they are to achieve their desired impact.



**From Mr. Brown's Class  
Child Street School  
Warren, Rhode Island  
Third Grade Activity**

**Integrating Science with Language Arts and Mathematics**

*The third grade at Child Street School is using a recycling/composting thematic unit that includes many hands-on activities. The students start by reading literature. Small groups discuss their books and then must involve the class in an activity. For example, after reading *The Lorax* the class might be asked to brainstorm a list of present day 'thneeds' that threaten our local environment and then suggest 'thneed' alternatives that are environmentally friendly. *Where Does the Garbage Go?* might lead to a day when students bring in 'throw aways' found in their families 'safe' trash and present new uses for them. Collecting and organizing the litter thrown away at lunchtime is an exciting mathematics activity for the students. Litter is sorted and classified, and the results are analyzed and displayed on graphs and charts. Each group participates in two major hands-on activities. The first activity explores the process of making compost in a plastic soda bottle. The second activity is similar. Each group of students makes a model landfill to compare the rate of decomposition of various materials. A plastic or glass jar with a lid is used. This thematic unit could culminate with a field trip to the Johnston Landfill (tel. 831-4440). The Rhode Island Solid Waste Management Corporation gives recycling information and composting demonstrations.*

**Suggested Literature Resources for this unit:**

*The Lorax* by Dr. Seuss  
*Where Does the Garbage Go?* by Paul Showers  
*Just a Dream* by Chris Van Allsburg  
*Mrs. Fish, Ape, and Me, the Dump Queen* by Norma Fox Mazer  
*Waste* by Christina Milles by Louise Berry  
*Garbage* by Karen O'Conner  
*Trash!* by Charlotte Wilcox  
*Jack, the Seal, and the Sea* by Gerald Aschenbrenner  
*Worms Eat My Garbage* by Mary Appelhof  
*50 Simple Things You Can Do to Save the Earth* by John Javna et. al.  
*Recyclopedia, (Games) Science Equipment, and Crafts from Recycled Materials* by Robin Simons

Learning activities outside the school building and beyond the normal school day should complement and enrich science learning for all students. For this to be successful, communities must support the work of non-profit organizations, museums, libraries, nature centers, and other science education opportunities provided by the 'informal' science education sector. Parents and other significant adults in children's lives must be more fully engaged in expanding both their own and students' knowledge of science (McCaleb, 1994; Swap, 1993). A variety of national programs, competitions, internships and scholarships are also available to students to expand their awareness of and experiences in science (Grand, 1994).

#### Exploration, Dialogue and Discourse Promote Understanding

Learning is interactive and occurs in a social context. The vision is to transform the classroom into a learning community where ideas are shared, evidence is used to strengthen ideas, and there is willingness to change ideas through exploration, dialogue, and discourse.

Teachers should provide students with many opportunities to explore scientific phenomena, using examples from their everyday experience. Exploration allows students to become familiar with materials and ideas in open discussion with others. Through exploration students apply their understandings and develop explanations by experimenting. It is also a way for students to answer their questions and to formulate hypotheses.

Teachers organize the classroom. They set the social norms for discourse to help students develop understanding from experience with materials in the classroom as well as from their out-of-school experiences. As one science educator described it: "There must be opportunity for independent exploration, as well as guided group activity, for quiet reflection and for animated discussion. Small group work enables every individual to participate fully in activities and discussion, and allows children to develop leadership skills, to learn from one another, and to take intellectual risks" (Bird, 1992). Research on cooperative learning indicates several positive effects of small group, student involved or led, hands-on science lessons. However for small group cooperative learning the teacher must carefully plan the learning environment; "... it takes time and practice for teachers to become skilled in its use" (Blosser, 1992). Large group work brings students together to share a variety of ideas similar to professional scientists collaborating on an investigation. Through a combination of large group and small group work the teacher designs the classroom environment to promote experiential learning.

*"Education must be inclusionary, emphasizing parental and community involvement, intra-agency cooperation and collaboration, and partnerships with business and labor. These collaborations must begin at the grassroots. Parents, joined by business and community leaders, must serve as informed participants, meaningfully involved in decisions about outcomes and judgements concerning success of schooling."*

*Educating ALL Our Children, A Report of the 21st Century Education Commission, March 1992.*

*"Parental and adult participation in the school could be fostered by:*

*. producing school publications and information in several languages;*

*. organizing an orientation event before the start of each school year;*

*. giving each parent/adult a school calendar and a handbook of school personnel and programs;*

*. introducing parents/adults to all available parent organizations and services;*

*. arranging a personal welcome from the administrative staff; and*

*. ensuring early individual contact between parents and teachers."*

*Rhode Island's Choice: High Skills or Low Wages, RI Skills Commission, May 1992.*

Discussion among a small group of students or between student and teacher, and the framing of ideas and arguments to support a particular point of view, is an important strategy for developing students' conceptual understanding. Every effort should be made to have children ask questions and then use their questions to further their investigation. By posing questions, teachers may assist children to confront their assumptions and lead them to follow new paths of inquiry.

#### Key Concepts and Ideas of Science Should be the Focus

A transformation in science curricula is occurring from coverage of a large number of facts and terminology on many topics to more in-depth study of fewer, major concepts. Major scientific ideas or concepts and thinking skills need to be emphasized. Less attention should be paid to specialized vocabulary, memorized facts, and procedures. Project 2061 of the American Association for the Advancement of Science, the National Science Teachers Association's Scope, Sequence, and Coordination of Secondary Science project, and the National Science Standards recommend that instruction cover the main ideas of science and the interrelatedness among various phenomena within the disciplines. The goal is to provide a greater depth of understanding.

There are different schemata for organizing science content around topics and relating units often taught in various grade levels to the larger ideas of science. Project 2061 identifies four common themes that pervade science, mathematics and technology (scale, systems, constancy and change, and models) and suggests that science curricula should be centered around these themes. A conceptual approach to science would suggest science concepts (such as diversity, variation, order, structure, function, and change) as a way of integrating diverse topics. Other reports suggest different organizing principles, but the common element from research and studies is that the curriculum highlight major ideas, concepts, or themes, "the big ideas," so that detailed information about science becomes connected, becomes meaningful, and contributes to successful problem solving (Loucks-Horsley, et al., 1990).

More time can be spent on developing understanding of the major concepts illustrated by the topics. An illustration of how a unit on seeds can build understanding of a major idea is found in the Life Lab Science Program for elementary science education. The first grade theme of this curriculum is diversity and cycles. A unit on investigating seeds would compare and contrast seeds, monitor germination, and begin to predict the outcome of simple experiments. A study of soil and the diverse plants and animals living in it expands upon the original theme. Life, physical, and earth sciences are connected around this major idea.

## The Role of the Teacher

The role of the teacher is being transformed from one of primary dispenser of knowledge to one of being a facilitator of learning. This is a more demanding role in many ways. The teacher provides information in the context of a rich learning environment, in which the student is an active learner. Rather than the teacher telling the students what they are to learn, the teacher sets up an environment where the student can be active in acquiring knowledge, mainly through the process of experimentation and discourse.

The teacher engages students in problem solving by asking probing questions, promoting inquiry, and guiding discussion with use of hands-on materials. Facilitation also requires the teacher to be familiar with resources whether they be curriculum materials, technology, community members or professional colleagues with special expertise, or institutional resources such as museums or science centers, and a capacity to draw on these resources as the need develops. "When students' investigations lead them down an exciting but unexpected path, having experimental materials or reference tools at hand or having a knowledgeable colleague to call on can turn a 'teachable moment' into a lifetime of understanding. Good teachers are accustomed to responding to children's short and long-term intellectual and emotional needs, but to do so in the context of scientific inquiry requires a special kind of preparedness and sensitivity" (Bird, 1992). It takes a deep understanding of basic science concepts and a willingness to not always be the 'authority' and to be comfortable teaching science in an experimental mode.

For teachers to be successful facilitators of children's science learning a great deal of support must be made available to them both within the school and from the broader professional community. They cannot do this without support from professional colleagues. They must have opportunities to exchange ideas and experiences with other teachers and with colleagues from the science and education community, to reflect on their teaching, to read research and contribute to it as part of a research team.

## Appropriate Staff Development

The teacher is key toward improving instruction. Since teaching for understanding demands a role that the teacher's preservice training often did not model, opportunities for inservice training are essential in transforming science instruction (Fitzsimmons and Karpelman, 1994). While very capable, teachers often have not had a college program that provided a basic background in the physical, life, and earth sciences and the ways to teach science to promote understanding. Teachers do not need to be experts in

*"The student as lifelong learner will possess skills, knowledge and attitudes of:*

- . Literacy - reading, speaking, listening, writing, and mathematics;*
- . Thinking - the ability to think creatively and critically, make decisions, solve problems, see things in the mind's eye, know how to learn and reason;*
- . Self-reliance - understanding one's own strengths and talents and having confidence in the ability to shape one's own future through one's own efforts;*
- . Intellectual curiosity - interest in and enthusiasm for learning; the habit of questioning; the ability to form independent judgements and theories;*
- . Versatility - ability to express oneself in more than one medium.*

*Educating ALL Our Children, A  
Report of the 21st Century  
Education Commission, March 1992*

*"Schools must be centers of learning, student-oriented and accountable for student performance. The Department of Education is committed to supporting schools and districts which dedicate their efforts to improving student achievement through school-based management by allowing them more flexibility to decide how best to achieve good results in the classroom."*

*Reaching for High  
Standards: Student  
Performance in Rhode  
Island, RI Department of  
Education, December 1993.*

*"National research and practice tell us that teachers, working together and recognizing the social and academic needs of their students, can produce results that differ very little among economically diverse students. We believe that high expectations, appropriate instruction, strong professional development programs, and an orientation to building upon students' strengths will result in the closing of achievement gaps over time.*

*Teachers must show leadership by constantly seeking school improvement, promoting and employing the best practices to reach students and ensuring that the learning experience is child-centered. They must be role models for lifelong learning, taking part in professional development and in-service training. They must also take the lead in working with all stakeholders in a child's education - administrators, school committees, parents, and the public - to assure that all students do learn."*

*... Reaching for High Standards: Student Performance in Rhode Island,  
RIDE, December 1993.*

every aspect of science; in fact most scientists are experts in only a narrow speciality. But they do need a general background in science content. All teachers should be better prepared in science content, pedagogical science, general knowledge of pedagogical principles and practices, curricular knowledge, knowledge of student diversity and individual differences, and professional policy and ethics.

It is most important that the inservice instructors model the teaching strategies they wish teachers to use. In addition, time for the teachers to practice new teaching behavior and continue to work with mentor colleagues is also a part of a good inservice program. Further, teachers will need to have regular opportunities to plan and collaborate with their fellow teachers at professional meetings such as national and state science teachers' meetings and at the district level.

Teaching for understanding takes not only time to learn but also support from other colleagues and the school administration. Meaningful change in teacher behavior may take years. Teachers experimenting with new strategies and programs need the time and resources to try new techniques to determine what works best. Teachers exchange ideas and they need to use the same methods to learn to teach science as the students need to learn it.

The most effective staff development activities:

- \* are continuous and on-going;
- \* are embedded within the regular school calendar, not after school or during the summer;
- \* model the constructivist approach to teaching that teachers will use with their students;
- \* provide opportunities for teachers to examine and reflect on their present practices and to work with colleagues to develop and practice new approaches; and
- \* provide good support structures within the group, among the group and the instructors, and from the school.

#### Assessment must Align with Goals for Instruction

A view of assessment as the servant not the master of curriculum is transforming assessment practice (see the subsequent section on assessment). Assessment and instruction are closely linked. Since teachers experience pressures to teach to the test, the prevalence of assessments that don't test for conceptual understanding or are limited to isolated facts has led to a curriculum that focuses on factual knowledge and vocabulary

(Madaus and West, 1992). In this way students learn discrete pieces of information and unconnected facts.

A new link between assessment and instruction is being forged through the science education reform movement (Hein, 1990). By using more authentic assessments such as performance-based or portfolio assessment or multiple choice tests that require thought beyond recognition and recall, more higher order thinking skills can be assessed, and students can learn through the process of assessment itself (Wheeler and Haertel, 1993). Children must be offered many different options for learning and communicating what they know and understand, and for raising new questions about a subject. Occasions to demonstrate ideas, quantify results, and make written, oral, kinesthetic, or visual presentations of findings and hypotheses are essential (White and Gunstone, 1992; Herman, Aschbacher and Winters, 1992). The important consideration is that the assessment measures progress toward the goal of the instruction.

#### Families and Other Concerned Adults Play Important Roles

The rise in informal science education opportunities and the strong influence of the family and other adults on children's science learning has the potential to transform science learning (Swap, 1993). Families and the community can encourage children's study of science both in school and in other science education activities. They can do this by supporting children in their homework, carrying out science activities at home, and participating in the growing number of informal science activities at zoos, museums, nature centers, national and state parks, and community organizations such as 4-H clubs. If families view science as an important subject for all students, they will more likely promote science activities for their children both in school and out of school. Often parents and other members of the community can bring their experiences to enrich the curriculum.

The availability of informal science education activities for young people has increased dramatically in the last few years. They vary in format from "Science by Mail," a program produced by the Boston Museum of Science, to the "Voyage of the Mimi" and "The Magic School Bus" televised science programs. Other programs help adults and children work together on science in out-of-school activities. The Family Science Program from the Lawrence Hall of Science at Berkeley (see organizations listing) encourages fun with science as a family activity. The U.S. Department of Education has published the booklet "Helping Your Child Learn Science" with many excellent opportunities to engage children in science and the National Urban League has a current project underway to expand parent attention to mathematics and science (see the latter part of the section "Organizing the System to Support Quality Science Education").

*"Students can respond to performance-based assessment in a limitless number of ways, encouraging creativity as students work toward high standards. Performance-based examinations can assess a more complex understanding of material that is not easily reflected in standardized testing. Performance-based assessments also allow for revision that is not possible in a one-time test."*

*In working on a project, students might form teams and select team leaders to investigate a problem. Students on the team might perform different tasks, such as testing the hypotheses, documenting the experiments, or presenting the findings. A student working on an individual project might prepare interim reports of a work-in-progress, leading to a final project that represents a year's worth of research and experimentation."*

*... Rhode Island's Choice:  
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